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GENETIC RESEARCH IN SPACE

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16. Abstract

The role of the genetic apparatus in the adaptation of the organism to conditions of weightlessness is studied. The investigation includes studies at the gene level, studies at the chromosome level, studies at the cell level, studies at the tissue level, studies on the organism level, and studies at the population level.

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INTRODUCTION

As we know, the effect of prolonged weightlessness on the hereditary /2
structures of various biological subjects has been studied for about three decades. We may conditionally define three periods in the study of the genetic (cytogenetic) effects of this factor, three stages which differ in their goals, tasks and methodological approaches, as well as by their level of technical provision of flight experiments.

In the first period, which preceeded man's flight into space, biologists had to answer the question of whether weightlessness was a lethal factor or a strong mutagen. An analysis of the results of experiments performed during this period allowed us to conclude that weightlessness is not an extremal factor for genetic structures. The practical importance of this conclusion is evident.

The start of the second period may be related to the flights of cosmonauts P. Popovich, V. Bykovskiy, and B. Yegorov, who performed a series of interesting biological experiments in space. This period was longer than the first in its duration. Among the number of problems solved by biologists during this period, the primary one was the problem of determining the effects of weightlessness at the chromosome and cell levels.

Such effects were found on a number of biological objects. Thus, specifically, the effect of weightlessness on the segregation of chromosomes and the process of cell differentiation were demonstrated on the microspores Tradescantia paludosa, while aneuploidy was demonstrated for Dr. melanogaster. Certain plants exposed on spacecraft showed the effects of stimulation of the growth processes, as well as change in the form of the cells. These effects were small in value, but statistically reliable. They were also confirmed by a number of foreign studies.

The third period begins with the study of the entire problem of variability /3
under weightlessness, for which a set of methodological approaches is proposed to unify the research from the gene level to the population level.

One of the primary tasks of this period was the study of the role of the genetic apparatus in the adaptation of the organism to conditions of weightlessness, and ultimately in determining the role of gravitation in the evolution of life on Earth.

The basic directions of the research contain six sections, which include various methodological approaches.

The leading institution in the implementation of these studies was the Institute of Medico-Biological Problems, USSR Ministry of Public Health, while the researcher in charge was Professor V. V. Antipov.

BRIEF CONTENT OF SECTIONS

1. "Studies at the gene level". This section unites a set of experiments in which the study of the effect of space flight factors, including weightlessness, on the amplification of genes of ribosomal RNA is planned. This process has been studied in detail for many biological objects in oogenesis on genes 28 and 18 of rDNA, and is a directable process. We also know that flight conditions may cause the stimulation of rDNA gene activity. The notion is expressed that the application of this approach will make it possible to obtain data on the mechanisms of growth stimulation and reparation processes at the gene level under conditions of weightlessness. The amplification of rDNA genes will be studied in the oocytes of fish, amphibians, reptiles, and insects.

2. "Studies at the chromosome level". Planned in this section is the application of six methodological approaches, which may be conditionally designated as:

--"additional chromosomes";
--"crossing over";
--"conjugation of chromosomes"; /4
--"differential coloration of chromosomes";
--"interphase nucleus"'
--"effect of gene position".

Additional chromosomes have not yet been used for studying the effect of weightlessness on the cell. At the same time, a study, for example, of the effect of cold on additional chromosomes of tradescantia clone convinces us that this is a good model which may be used (by means of simple counting of chromosomes in the metaphase) to understand the complex events taking place in the interphase during the regulation of gene blocks. This method will be used in experiments on plants and mammals.

Crossing over is a widely studied method which is used well in studying the genetic effects of space flight factors, including weightlessness. An analysis

of the obtained data allows us to consider its further application expedient. Here, it is necessary to expand the possibilities of the method, for which in future flight experiments it will be necessary specifically to increase the number of marker genes, and in connection with possible interference to consider the process of coincidence. The most convenient object for these studies are insects.

Chromosome conjugates. The effect of weightlessness on mitosis and meiosis has been studied in numerous flight experiments on a number of biological objects. The obtained results testify to the necessity of continued, more in-depth study of these fundamental processes under flight conditions. The prophase of meiosis deserves particular attention. In order to study these processes, it is first of all expedient to use plants and insects.

Differential coloration of chromosomes. The study of C-disks, heterochromatic sections determined with the aid of a certain method of coloration /5 of metaphase chromosomes is of particular interest. We must stress the fact that heterochromatization of sections of chromosomes and then the removal of heterochromatin blocks is an indicator of adaptation taking place in the organism at the chromosome level. When the block of heterochromatized genes is reduced, new possibilities for transcription are liberated. This is particularly true of tandem located multiple genes, which as a rule are found next to the heterochromatin sections. Research using this methodology is most expediently performed on man and mammals.

Interphase nucleus. The location of heterochromatic sections on metaphase chromosomes gives not only a certain understanding of what place the heterochromatin occupies in the structure of the interphase nucleus and what amount it is found. However, the interphase nucleus is a "working" unit, since it is specifically here than transcription takes place. Metaphase chromosomes are merely an "echo" of the events taking place in the interphase. A study of the degree of condensation of chromatin in the interphase nucleus is possible with the aid of an electron microscope and other methods with the application of molecular-genetic methods. The interphase nuclei may be studied in any tissues. The epithelial cells of rat kidneys may present the greatest interest in this respect.

Effect of gene position. Depending on where the gene is in the chromosome, it may change its transcription capacity. With chromosome restructuring of the

inversion and translocation type, genes may change place, and in a number of cases this is expressed in the indicators of the organism. We might think that this effect occurs because of where the gene is in the nucleus, since here the nonspecific regulators of gene activity begin to play an important role. The location of zones of chromatin concentration in the nucleus turns out to be significant. There are well studied models for experiments with the effect of gene position. This is first of all the gene white in the I chromosome of fruit flies. We may presume the same developed scheme for the gene pink in /6 Tredescantia.

3. Studies at the cell level. This section includes a set of experiments whose goal is the study of the effect of space flight factors, and primarily weightlessness, on the position of the nucleus in the cell. As we know, the nucleus always occupies a certain place in any variably differentiated cell. The change in position of the nucleus in the cell leads to a change in its homeostasis. The role of the cytoskeleton, the cell and nuclear membranes, the redistribution of energy in the cell metabolism and in the work of the genome is very great. The change in the form of the cell under weightless conditions and the change in position of the nucleus of the cell discovered by a number of authors is reflected in its differentiation. Excessive water retention of the cell under conditions of weightlessness, disrupting its size, also leads to a change in the position of the nucleus within the cell, changing undoubtedly also the interrelations in the heterochromatin-membrane complex.

A convenient model object for studying the effect of the position of the nucleus in the cell may be target cells.

4. Studies at the tissue level. The basic methodological approach used in this section is the study of the effect of weightlessness on the quantitative interrelations of the group of cells forming the tissue. As we know, the tissue consists of a number of different cells. And only their correct quantitative interrelations create normal structure and function of the tissue. A disruption in the precise quantitative relations of various groups of cells in relation to one another leads to a disruption in the functioning of the tissue. The most remarkable thing in this case is that each individual cell may remain quite normal for a long time, without altering its homeostasis. In this case, the regulators of a higher level are significant, specifically the neurohumoral and

immune regulators. Any disruption in the regulation of the numerical relations of the groups of cells comprising the tissue leads to their degradation. The model objects here should primarily be the tissues of mammal cartilage and bone.

5. Studies on the organism level. The basic methodological approach used in this section is the study of the gene reaction norm under conditions of weightlessness, i.e., the spectrum of indicators which may appear during the action of a given gene. It is a rather complicated path from gene to indicator. The indicator is formulated under the effect of heredity as well as under conditions of the environment. Some genes have a narrower reaction norm, others a broader one. There is also a so-called alternative reaction norm, when under the effect of extremal factors the indicator of opposite value is manifested. For example, instead of white hairs on the coat of the Himalayan rabbit there are black ones, instead of red flowers on a primula there are white, etc. The manifestation of new indicators due to the reaction norm may be expected also under conditions of space flight. The most suitable model for use as object of study are plants, for example, tradescancia clones, which under optimal conditions have blue flowers, and when kept in cold--cream colored flowers, since the alternative reaction norm is clearly manifested here.

6. Studies at the population level. The process of formulation populations and their dynamics comprises microevolution. A population, as we know, is formed due to variability and selection. The selection occurs according to hereditary indicators as well as according to modifications. Under conditions of weightlessness, variability as well as selection may follow a different course than they do on Earth. Adaptation is partially determined by the effect of the environment, but primarily it is determined genetically. Polymer genes, which generally participate in the development of quantitative indicators, create broad possibilities for polymorphism. Only those individuals can survive and multiply whose genotypes give them certain advantages.

The predominant genotype in a population corresponds most of all to the /8 requirements of the specific environmental conditions. The size of the population plays an exceptional role. In small populations, the effect of genetic-automatic processes sets in, with random drift of the genes. This must be kept in mind when computing the number of individuals in a population.

Research must evidently begin with the performance of experiments on fruit flies under conditions of weightlessness, creating overpopulation in the cultures.

This leads to the strong action of selection. This is the first step in directing the study of limited populations and formulating ecotypes under conditions of weightlessness. The obtained results will determine the scheme for subsequent studies to be performed in this sphere.

In conclusion we must note that the tasks have been set with consideration for the results of genetic research in space performed over the last 30 years, and also with consideration for the latest achievements in current genetics.

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BASIC RESEARCH DIRECTIONS

No p/p	Name of section	Object of study	Spacecraft	Leading scientific institutions
1.	"Studies at the gene level"	Fish, amphibians, reptiles, insects	Biosatellites 1987, 1989, 1991	Institute on Biological Development im. N. K. Kol'tsov, AN SSSR
2.	"Studies at the chromosome level:	Man, animals, plants	Manned stations, Biomodule, biosatellites 1987-2000	IMBP USSR Ministry of Health, Institute of Medical Genetics, USSR Academy of Medical Sciences
3.	"Studies at the cell level"	Mammals, plants	Biosatellites 1989-1991	Institute of Botany imeni N. G. Lodnyy, UkSSR Academy of Sciences
4.	"Studies at the tissue level"	Mammals	Biosatellites 1989-1993	IMBP MZ SSSR
5.	"Studies at the organism level"	Plants	Manned craft, Biosatellites 1989-1993	IMBP MZ SSSR
6.	"Studies at the population level"	Insects, plants,	Biomodule, biosatellites 1989-1995	Institute of Common Genetics imeni N. I. Vavilov, USSR Academy of Sciences.

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